IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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Applicant	:	Susumu Noda, et al.	
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Customer No.	:	29453	

Honorable Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

REPLY Under 37 C.F.R. § 1.111
Accompanying Request for Continued Examination
Under 37 C.F.R. § 1.114

Sir:

In response to the Office action, made final, of October 31, 2005 in the above-identified patent application, consideration of the following remarks is earnestly solicited.

The following remarks are new over Applicants' remarks that were submitted in their reply of February 28, 2006 but which, in the advisory action of March 13, 2006, were deemed not to place this application in condition for allowance. Because these remarks are new, they are believed to constitute a submission as required under 37 C.F.R. § 1.114(a), defined in § 1.114(c), and as set forth in MPEP 706.07(h), "Request for Continued Examination (RCE) Practice." Therefore, it is respectfully submitted that the RCE that this reply accompanies is proper. (The RCE is being filed on May 1, 2006 along with a petition for a three-month extension of time, and is therefore timely filed.)

Remarks begin on page 2 of this paper.

REMARKS

Status of Claims

Claims 1-11 remain pending in their form resulting from Applicants' amendment dated August 12, 2005 in the present application. In particular, Claims 1 and 2 were amended for editorial clarity, while claims 3-11 were left in their original form as filed.

Claim Rejections under 35 U.S.C. § 103

Claims 1-11; Akahane et al. (*Applied Physics Letters*) in view of Srinivasan and Painter (*Optics Express*)

Claims 1-11 remain rejected, by the October 31, 2005 Office action, made final, as being obvious over Akahane in view of Srinivasan.

Review and Rebuttal

In response to the final Office action, on February 28, 2006, Applicants filed a reply presenting arguments to the effect that in the Office's § 103 rejection of the claims, a *prima facie* case of obviousness has not been made. In the advisory action of March 13, 2006, however, Applicants' arguments were deemed not to place the present application into condition for allowance.

Applicants noted the Offices' verbatim repetition from its first action on the merits of its present § 103 rejection, save for the insertion of the words "in view of Srinivasan" in between the words "Akahane teaches," and also noted the Offices' stating, "The motivation would have been to increase the Quality factor of the filter." Applicants then rebutted that these assertions were not a prima-facie showing of a motivation in Akahane et al. to combine the teachings therein with those of Srinivasan.

Applicants made the point that the alleged motivation is not in the primary reference, i.e., Akahane, merely to underscore Applicants' rebuttal that the alleged motivation itself would not lead a person skilled in the art to combine the teachings of the references and arrive at the present invention. Yet in the advisory action, the Office answers, "The motivation to combine references need not be found in the text of the primary reference."

Admittedly, Applicants' rebuttal might seem to have been relying exclusively—and thus too limitedly—on pointing out that the suggestion that the Office alleges is a motivation to combine the teachings of the Srinivasan and Akahane references is in Srinivasan, not Akahane.

Nevertheless, Applicants were not attempting to argue that a *prima facie* obviousness case alleging a motivation to combine primary and secondary references is ruled out merely by the "directionality" of that motivation—that is, the secondary reference motivating a turning to the teachings of the primary reference, as opposed to the converse.

Finally, Applicants must for the record address the Office's advisory-action allegation that on page 4 of Applicants' February 28, 2006 reply, Applicants "admitted" a motivation to combine, apparently because there Applicants wrote,

> Yet although this may clarify that the Office is alleging a motivation to combine, that motivation in the first place is in Srinivasan, not Akahane.

It would seem that, because applicants wrote "that motivation in the first place is in Srinivasan," the Office asserts that Applicants "admit" that there is a motivation in Srinivasan to combine the teachings therein with those of Akahane. The Office's assertion is misguided, because taken in proper context, what Applicants wrote means "that *alleged* motivation is in Srinivasan."

New Arguments

The motivation that the Office has asserted for combining the teachings of the Srinivasan and Akahane references bears repeating: Section 3 on page 673 of Srinivasan begins,

> There are a number of ways to limit the presence of the small in-plane momentum components in the localized resonant modes of PC slab WG defect cavities. For example, the geometry of the defect and the surrounding holes can be tailored to reduce the magnitude of these components, as was done in [16], where the authors report a predicted *Q* of 30,000.

It is this second sentence in particular that has been cited by the Office as a motivation to combine the teachings of the Srinivasan and Akahane references. (Line 6

of the abstract on page 670 has also been cited; that line appears in the following sentence:

> The results of a symmetry analysis of defect modes in hexagonal and square host photonic lattices are used to determine cavity geometries that produce modes which by their very symmetry reduce the vertical radiation loss from the PC slab.)

Reducing radiation losses—not only vertical losses but also, in 2-D photonic crystal technology to which the present invention is directed, in-plane losses—thereby to improve the quality factor (*Q*) of the device that the photonic crystal constitutes is as general a motivation in the rapidly developing photonic crystal art as is, say, the motivation to improve the processing speed of integrated circuits.

It is a given that Srinivasan and Painter are concerned with improving the *Q* of photonic-crystal (PC) cavities, just as it is a given that Akahane et al. are concerned with improving the *Q* of channel add/drop filters combining a PC cavity and waveguide, because every other skilled person in this art has the same concern. Consequently, such a generalized motivation would arguably lead a person skilled in the art to combine any teachings of a given publication in the art with those of any other.

So the question vital to disposing of the present application is not where lies the motivation given by the Office for combining Srinivasan and Akahane to reject Applicants' claims to the present invention—the question is not whether the given motivation is in the primary or the secondary reference—because in fact such a motivation informs the entire PC art; the question is where do the motivations in the Srinivasan and Akahane references direct a person skilled in the art?

More specificity is called for, and in fact the directions in which the Srinivasan and Akahane teachings each motivate are as divergent as they are specific, as will now be shown.

It will be shown that a skilled person in the art learning from Srinivasan would be barred by the Srinivasan teaching itself from applying that teaching to the technology disclosed in Akahane. That such is the case is what Applicants' February 28, 2006 arguments "directed toward the methodology and theory of defect alteration taught in the applied references," as characterized in the comments appended to the advisory action, endeavored to demonstrate.

Even if a person skilled in the art were to attempt to combine the teachings of Srinivasan and Akahane, that person could not arrive at the present invention, because

Akahane and the present invention are directed to cavities of such a different structure from the cavity structure with which Srinivasan is concerned that a person skilled in the art wanting to improve the *Q* of an Akahane channel add/drop filter would realize he could not turn to Srinivasan to find the means to do so.

Put differently, the Akahane cavity structure itself rules out tuning the cavity according to the Srinivasan methodology.

Akahane et al. reviewed

Akahane et al. (Akahane) is directed to PC channel add/drop filters for wavelength-division multiplexed (WDM) optical communication systems. The paper notes that devices utilizing acceptor-type defects do not achieve *Q* high enough to provide the filtering resolution required for WDM applications, and that meanwhile researchers have concentrated efforts on improving the *Q* of defect cavities alone (rather than the *Q* of the cavity-waveguide system as a whole, functioning as a filter). Akahane then references Vučković et al. ("Design of photonic crystal microcavities for cavity QED," mentioned in Applicants' reply to the first Office action and also submitted to the Office by Applicants in their IDS of June 14, 2004) and another paper to point out that

> In such studies, the combination of the high *Q* factors and small mode volumes are considered very important since the goal is to realize high performance active light-emitting devices such as zero-threshold lasers, etc.

In the sentence succeeding the above-quoted sentence, Akahane then add,

> However, the requirement for the mode volume size is not essential for this channel add/drop filter [that is, the channel add/drop filters that are the focus of the Akahane paper] since it is a **passive** device, as long as the cavity is single mode for the concerning [sic] spectral range. . . . Instead we must consider the interaction between the defect cavity and the line defect waveguide.

(Emphasis added.)

Hence, the authors of the Akahane paper realized that passive PC devices have different design requirements from those of active devices—in particular that the mode volume limitations are not as severe—and determined to "investigate various donor

defects with one to three missing holes which are filled with the same dielectric substance as the slab."

Akahane et al.'s "L2" and "L3" defects, formed respectively by two missing air holes and three missing air holes, when tested in isolation (not in combination with waveguides) each demonstrated an approximately four-fold increase in *Q* over the defect with one fewer missing air hole. Then, referring to Fig. 2, the second column on the second page of the Akahane article discusses the relationship between *Q*, as given by in-plane *Q* and vertical *Q*, and the separation between the defect cavity and a waveguide as constituents of a filtering device.

The Akahane results seem to suggest that in applications in which the greater mode volume does not preclude a functioning device, the higher *Q* gained is advantageous. In particular, Akahane et al. found that the L3-based devices have very high filtering resolution and useful polarized emission characteristics.

In sum, Akahane et al. evaluated the *Q* of L2 and L3 (as well as L1) defect cavities in isolation, and the *Q* of the cavities combined with waveguides to function as filters. Regarding L2 and L3 defect cavities in isolation, Akahane is completely silent as to how the *Q* of the cavities might be improved—in particular, Akahane is totally silent about modifying the geometry of defect-surrounding holes. On the other hand, Akahane does investigate and discuss how the (L3) cavity-to-waveguide separation can improve *Q*.

- Thus, nowhere in Akahane is there any teaching or suggestion with regard to improving the *Q* of a donor-type defect cavity defined by three or more missing air-holes. The present invention as claimed achieves such improvement, despite the silence of Akahane on the subject.

<u>Srinivasan and Painter reviewed</u>

Meanwhile, Srinivasan and Painter (Srinivasan) is indeed not silent on the subject of improving the *Q* of defect cavities. But at the same time, Srinivasan is concerned with minimizing the mode volume to the extent possible—that is, "modal volumes approaching the theoretical limit of a cubic half-wavelength" (Introduction, end of first paragraph).

In particular, Srinivasan is directed to PC optical microcavities having "very small mode volumes and loss properties sufficient to sustain lasing" (Introduction, second paragraph, referring to an earlier study by Painter et al.) Clearly, Srinivasan is

concerned with active devices; in addition to mentioning lasers in the introduction, Srinivasan later mention "resonators":

> The use of such an analysis [one based on "dominant Fourier components and symmetry of a defect mode"] to produce approximate forms for the modes in hexagonal and square lattice PC defect cavities is the focus of other recent articles [13, 18], and as such, we primarily incorporate the results of these works and describe their implications towards the design of high-*Q* defect resonators.

(Section 3, second paragraph; emphasis added.)

> The results given thus far indicate that improving the loss properties of the defect mode resonators requires isolation of the mode's momentum components to regions outside the light cone to maintain a high $Q_{\perp}$, and to those regions for which the in-plane bandgap is substantial for a high $Q_{\parallel}$.

(Section 5, first paragraph; emphasis added.)

Thus, a design constraint on a defect cavity according to Srinivasan presents itself. That is, in order to minimize the defect mode volume so as to "approach the theoretical limit of a cubic half-wavelength," a point-defect according to Srinivasan must be designed according to the perturbation theory, which was explained by Applicants in their February 28, 2006 remarks. That is why, ultimately, Srinivasan teaches only two defect geometries, that of Table 6 and that of Table 7 in the Srinivasan and Painter paper. In both cases, *the dimension of the defect-constituting hole(s) is altered*. In the former case, the defect is constituted by a single hole that is enlarged diametrically; in the latter, the defect is constituted by a pair of holes centered on the defect's origin point and reduced diametrically. It is to be noted that the latter cavity structure is also a single-point based defect geometry. Moreover, it should be rudimentarily clear that, as applicants noted in their previous remarks, a defect in which the air holes are completely filled does not allow of designing based on perturbations—changes in size of—those holes, and consequently, the Srinivasan methodology is inapplicable to tailoring missing-hole defect geometries for enhanced *Q*.

It is respectfully submitted that PC devices according to Srinivasan—that is, PC resonators, as noted earlier—are limited to being constituted by the point defect geometries of Table 6 and Table 7, that is, to geometries of enlarging a single defect-constituting hole, or reducing twinned defect-constituting holes, in order to achieve the mode-volume minimization necessary for the functioning of the resonators.

In the present invention, in contrast, the defect is constituted by a plurality of three or more missing holes "of identical dimension and shape" to that of the rest of the holes in the lattice, except for the defect-surrounding holes whose dimension is altered according to the invention.

A defect according to the present invention is formed merely by leaving holes missing, *not* by altering the dimension of the defect-constituting holes. Therein Q is improved by the dimensional alteration of at least one nearest-neighbor defect surrounding hole (not any defect-constituting, missing hole), or by that alteration plus an alteration to a hole or holes immediately surrounding the nearest-neighbor holes.

Near the end of the Introduction to their paper, Srinivasan and Painter state that in section 5 they will

> consider further improvements in the designs based on a Fourier space tailoring of the defect geometries that reduces coupling of the mode's dominant Fourier components to components that radiate.

In section 5, (at the top of the page numbered 683 in their paper) Srinivasan and Painter then describe how this tailoring of the defect geometry is accomplished:

> Consider the graded lattice shown in figure 7(a). The standard defect holes at $(0, \pm a/2)$ have $r/a = 0.23$, while their immediate neighbors have $r/a = 0.253$. The hole radii are then increased parabolically outwards for 5 periods in the x-direction and 7 periods in the y-direction, after which they are held constant.

(The third sentence in the passage above has been quoted in both of Applicants' previous replies to the Office.) The gradating of the lattice by parabolically altering the dimension of the holes outwards for several periods from the defect is based on a methodology that precedes the Srinivasan paper. (Cf., for example, "Tuning holes around the defect" in the Vučković et al. paper cited earlier. Indeed, Vučković et al. is also directed exclusively to single-point defects.)

Nevertheless, nowhere does Srinivasan teach or suggest that the graded-lattice tuning of the defect cavities that are the necessary subject of their research would work on a defect that is *not* formed by a perturbation; nowhere does Srinivasan teach or suggest applying their methodology to the defect-surrounding holes of a cavity formed as in the present invention—a cavity having a mode volume beyond the size of interest in Srinivasan.

But this is not to argue that the present invention is such an application of the Srinivasan methodology; on the contrary, the present invention is a completely different, novel approach to improving the *Q* of a PC cavity—an approach necessitated by the totally different nature of the defect configuring that cavity according to the invention.

That methodology was set forth to a certain extent by Applicants in their reply of February 28, 2006, but is developed more fully by Yoshihiro Akahane, Takashi Asano, Bong-Shik Song, and Susumu Noda in "High-Q photonic nanocavity in a two-dimensional photonic crystal," *Nature*, vol. 425, 30 October 2003. This article was published well after Applicants' March 17, 2003 priority date, and apart from Bong-Shik Song, the three other authors are the three inventors of the present application.

A reading of the *Nature* paper indicates that by utilizing a one-dimensional model of an unmodified defect cavity of the present invention to analyze the electric field profile inside the cavity, the present inventors found that there was an abrupt change/attenuation in the electric field at the cavity lengthwise edges that led to large radiation loss. The inventors then developed a *Q*-enhancing methodology unique to their special cavities—cavities of three or more adjacent holes that are filled, or "missing." That methodology is succinctly captured in the pending claims of the instant application.

Lastly, it is to be noted that in their *Nature* article, the present inventors give an actual figure for the mode volume of sample cavities formed by "three missing air rods"—that is, formed according to the present invention. Inasmuch as Srinivasan also sets forth mode volumes—that is, V_{eff} in Tables 6-8—of the cavities Srinivasan and Painter analyze, a comparison of mode volumes of cavities according to the present invention with cavities as taught by Srinivasan can be made. Such a comparison, set forth below, serves as evidence of the totally different approaches taken by Srinivasan and by the inventors of the present invention to designing PC cavities and accordingly improving the *Q* of those cavities.

<u>Mode volume of cavities according to the present invention</u> (as set forth by the present inventors in *Nature*): 6~7 $\times$ 10^{-14} cm^3 =

0.06~0.07 μm^3

<u>Mode volume of cavities according to Srinivasan and Painter</u>: 0.11~0.43 "cubic ½ wavelengths." According to an earlier Srinivasan paper, 2.0 cubic ½ wavelengths ≈ 0.03 μm^3; therefore 0.11~0.43 cubic ½ wavelengths =

0.0017~0.0065 μm^3

- The 0.11~0.43 cubic ½ wavelength mode volumes of Srinivasan are clearly much smaller than (about **1/40** to **1/10** that of) the mode volumes of Akahane.

In sum, cavities according to Srinivasan are for active devices such as lasing resonators, and as such require mode volumes minimized to approach the theoretical limit of cubic half wavelengths. L3 cavities according to Akahane and cavities according to the present invention are in contrast configured by donor-type defects formed by three or more adjacent filled or missing holes, and have mode volumes 10 to 40 times larger than the mode volumes of the cavities investigated in Srinivasan.

To enhance the *Q* of the cavities to which their research is directed, Srinivasan and Painter in the first place alter (perturb) the geometry of the single-point defects themselves. To enhance the *Q* further while preserving the minimal mode volume of the single-point cavities, Srinivasan and Painter then apply the known methodology of tailoring the geometry of the defect-surrounding holes—specifically, they parabolically gradate the size of the holes for several defect-concentric periods by enlarging the holes' radii.

As is clear from the Srinivasan and Painter discussion, on page 683 of their paper, of their "chosen lattice," the relationship between the altered size of the defect-constituting hole(s) and of the size of the holes in the surrounding graded lattice is critical. (They mention that the relationship acts "as a potential well [to] confine the mode in real space.)

While Akahane measures the *Q* of an L3 defect, the reference is silent on improving the *Q* of a cavity constituted by the defect. Moreover, the methodology utilized by Srinivasan is inapplicable to an L3 defect according to Akahane, in the first place because the defect-constituting holes are filled; the defect is constituted simply by a run of missing holes, not by altering the size of a hole on a single point or of a twinned pair about a single point. The defect-hole/defect-surrounding-hole relationship crucial to improving *Q* in Srinivasan is not even available for improving the Q of cavity according to Akahane.

But whereas Akahane is silent on improving the *Q* of the cavities described and tested therein, the present invention involves the discovery—by Akahane himself and the other two inventors who are the Applicants in the present application—of a methodology for improving the *Q* of cavities comprising a defect constituted by a plurality of at least three filled lattice holes neighboring each other, as set forth in claim 1.

It is respectfully that at least for the foregoing reasons, the pending claims recite subject matter that is non-obvious over the Akahane and Srinivasan references.

A response to this Office Action was due by January 31, 2006, and consequently a Petition for Extension of Time, along with an authorization to charge to a credit card the fees due, accompanies this paper to ensure that this amendment is timely filed.

Accordingly, Applicant courteously urges that this application is in condition for allowance. Reconsideration and withdrawal of the rejections is requested. Favorable action by the Examiner at an early date is solicited.

Respectfully submitted,

May 1, 2006

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